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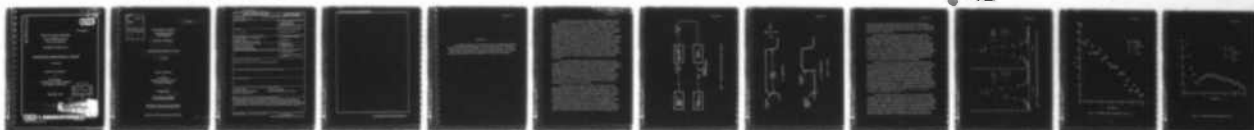
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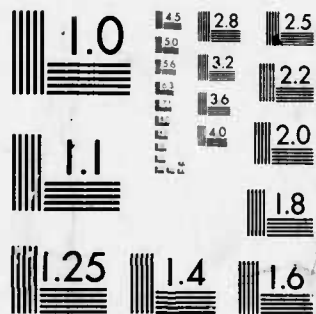
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Task No. NR 359-570

TECHNICAL REPORT NO. 3

NANOSECOND BREAKDOWN IN LIQUIDS ✓

J. M. Proud

Prepared for Publication

in

Annual Report
Conference on Electrical Insulation
and Dielectric Phenomena

September 1976

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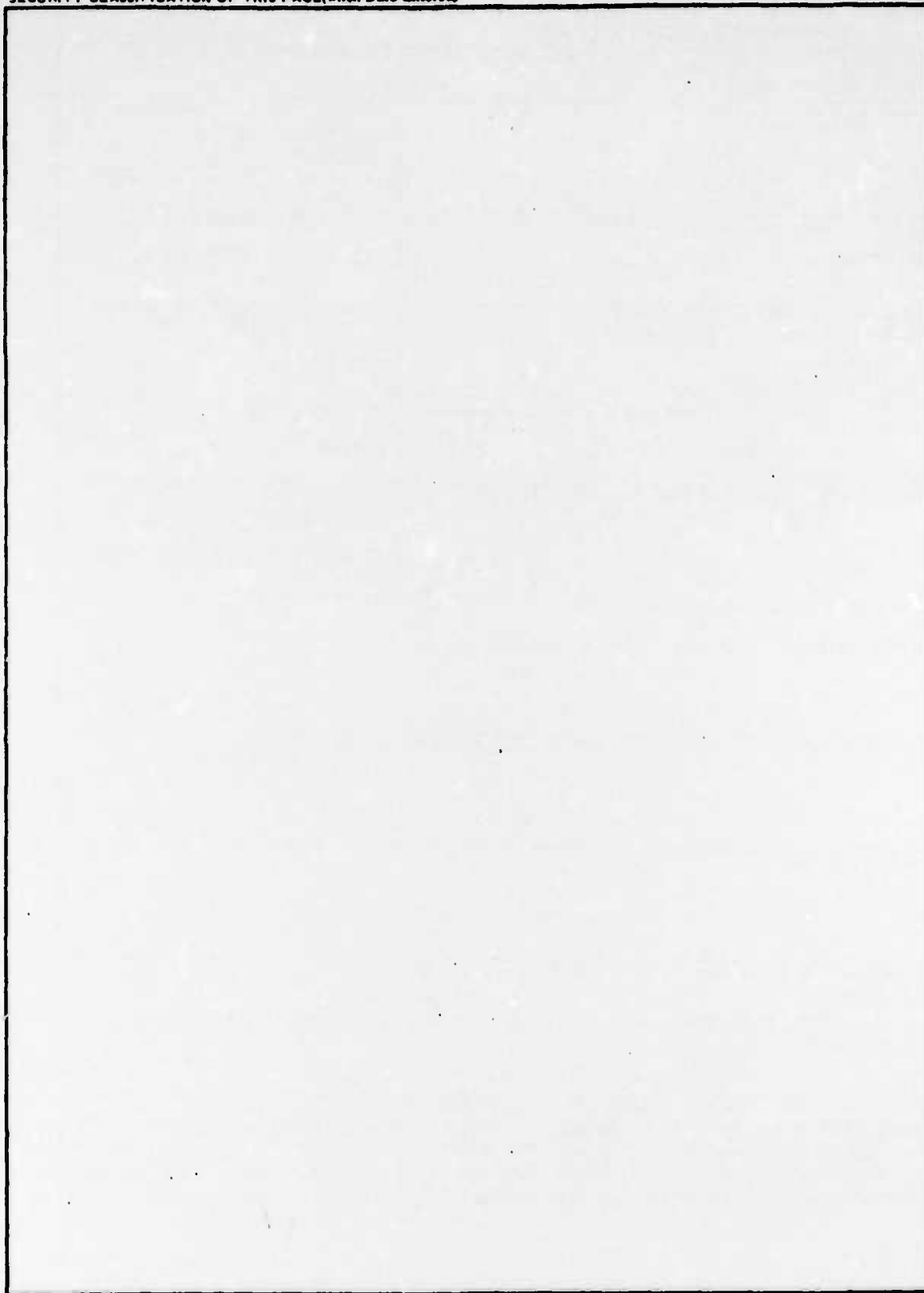
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ABSTRACT

The statistical properties of nanosecond time lags in the high field breakdown of several liquids have been investigated. The observed time lags are distributed in a manner which is characteristic of the molecule composing the liquid. The initiating mechanisms may involve molecular orientation at the liquid-electrode interface.

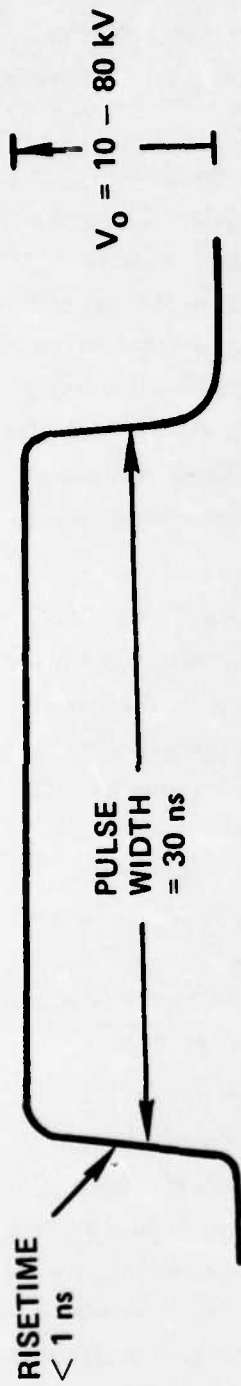
The incipient physical processes governing nanosecond breakdown in liquids may be conveniently studied with the aid of a statistical interpretation.¹ Thus, even though the physical processes are not known, it appears to be useful to divide the breakdown lag time into formative and statistical components. The approach has been successfully applied to nanosecond breakdown in gases² where Townsend α -processes are largely responsible for the formative lag time, while various mechanisms controlling the rate of appearance of electrons govern the statistical lag time component. Provided that several experimental criteria are met, the formative time for a particular gas can be assigned a discrete value which depends only upon the applied field and the pressure. The resulting separation of a single valued formative period and a distributed statistical time lag does not appear tenable in liquid breakdown. Instead, there is evidence³⁻⁶ that the formative component of lag time must, itself, be viewed as a distributed quantity. Based upon observations in n-hexane, it has been proposed that the formative time be described by a Gaussian distribution function about its mean value.⁷

The present investigation has explored the characteristics of the lag time distribution in the nanosecond time domain under high field conditions where formative processes are thought to be dominant. Liquids of several types have been investigated including a simple short chain hydrocarbon (n-hexane), an alcohol having similar chain length (hexanol) employed as an additive to n-hexane, an inorganic aprotic liquid (sulfur monochloride) and a fluorinated ether of high molecular weight (Freon E-3). The data for n-hexane support earlier findings as to the normal distribution of the formative process. However, non-Gaussian and apparently characteristic distributions are seen in Freon E-3 and in S_2Cl_2 .

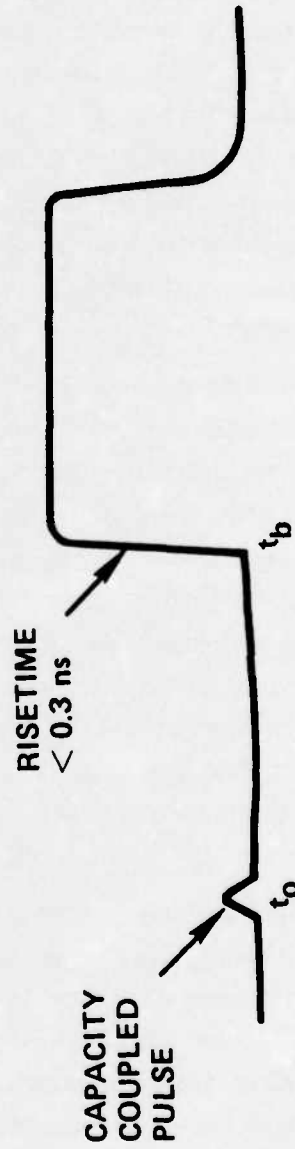
The experimental system (Figure 1) consists of a traveling wave pulse generator producing individual rectangular pulses having a width of 30 ns, a pulse height (open circuit) up to 80 kV, and a subnanosecond risetime (Figure 2). The test cell consists of tungsten electrodes shaped for approximate uniform field conditions in a gap space of 230 μ m with an electrode area of 8 mm². The coaxial system, including test cell, approximates a uniform 50-ohm impedance throughout. A capacity divider probe with a flat response from about 10 MHz to substantially beyond 1 GHz provides an accurate attenuated signal sample for oscilloscope recording. In operation a single pulse is launched by means of a solenoid valve which momentarily releases the pressure in the high pressure spark gap. When the rectangular pulse



Figure 1. Experimental Nanosecond Breakdown Apparatus



(a) Incident Pulse



(b) Transmitted Pulse

Figure 2. Test Pulse

reaches the test gap, a differentiated signal corresponding to the leading edge is passed by the capacitance coupling between test cell electrodes. The observed signal at t_0 then marks zero time and the breakdown lag time can be read for a single breakdown event as $t_b - t_0$ [Figure 2(b)].

Measurements of the lag time behavior were performed by repeatedly recording $t_b - t_0$ at constant pulse height over typically 500 to 700 trials. The cell was sealed during a test and the electrodes were maintained in the same relative position throughout. Some cumulative damage to the liquid (especially n-hexane) and to the electrodes was noted, but the breakdown characteristics remained unchanged over typical test runs. Samples of n-hexane and S_2Cl_2 were dried and distilled while Freon E-3 was used as supplied by the manufacturer. The procedure used in obtaining the distribution of lag times involved the computer sorting of the digitized data into 1 ns time bins. Computer plots of the experimental probability density function as well as the various integral curves (Laue plots) were then obtained.

Figure 3 shows the data representing the unnormalized probability density function for successive runs in pure n-hexane and in n-hexane with 1% hexanol additive. In both cases a theoretical Gaussian distribution having the same mean and variance as the experimentally observed distribution is plotted for comparison. While the experimental bin population is not large enough for conclusive characterization of the statistics, the tendency toward an approximate Gaussian distribution is in evidence. The presence of polar molecules in hexane is seen to have no influence upon either the average value or the variance. In fact, the experiment serves to demonstrate the high degree of repeatability in the data runs. Observations of the lag time distribution at progressively lower field strengths show rapid departures from Gaussian statistics. For example, a complex distribution with maxima at 8 and 20 ns is observed in n-hexane with a pulsed field of 1.8 MV/cm.

The results of similar experiments in Freon E-3 and S_2Cl_2 are illustrated in Figures 4 and 5. Although the average lag time is close to that found in n-hexane for nearly equal field strength, the experimental distribution in both cases is markedly non-Gaussian. The observed distribution in Freon E-3 is nearly linear, although with more complete statistics, one might anticipate that an exponential distribution would eventually emerge which would be characteristic of an underlying random rate process. The observed lag time might then be interpreted as one which is dominated by a statistical component, an additive to the statistical lag component associated with

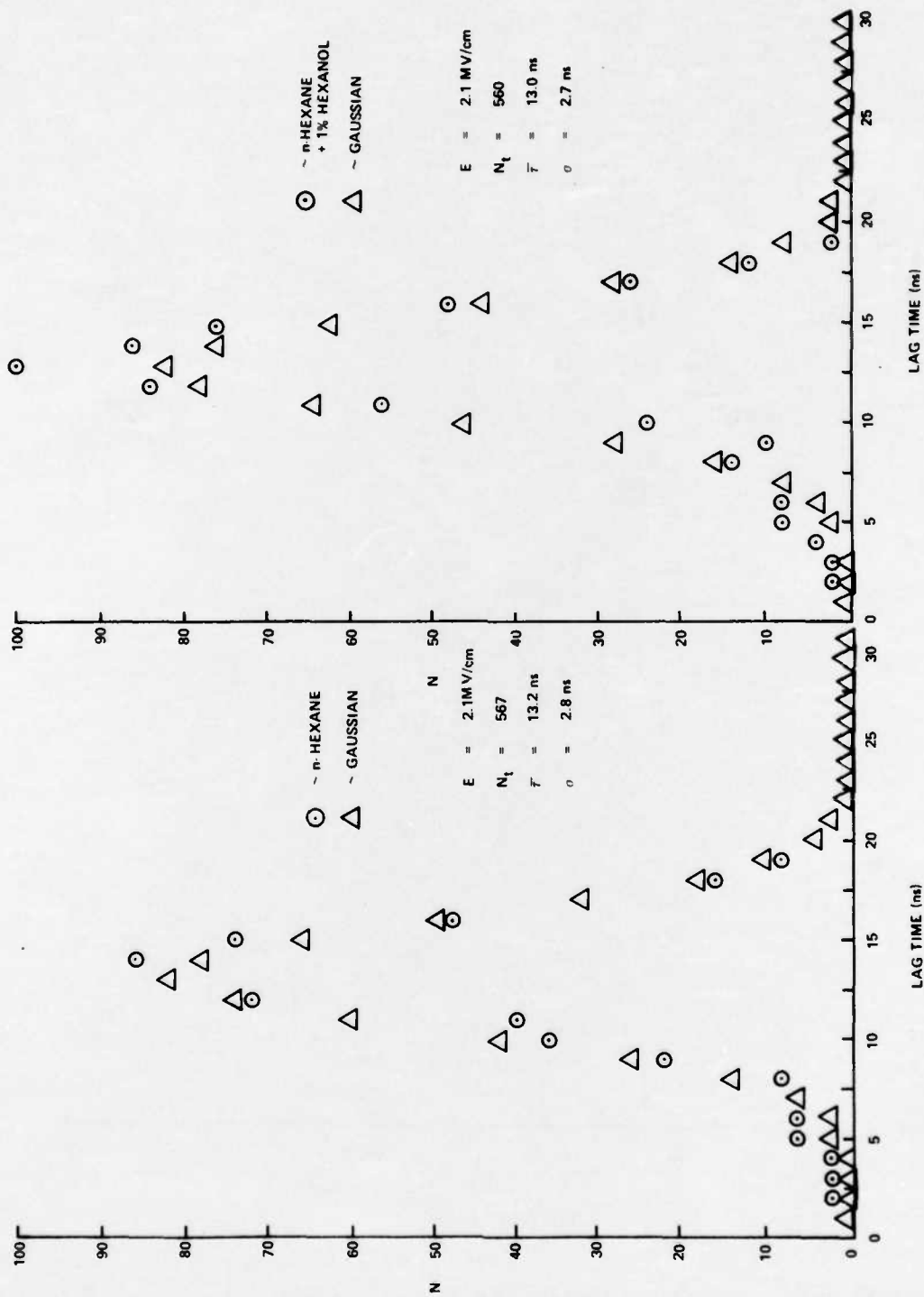


Figure 3. Experimentally Observed Probability Density Distribution of Lag Times for n-Hexane

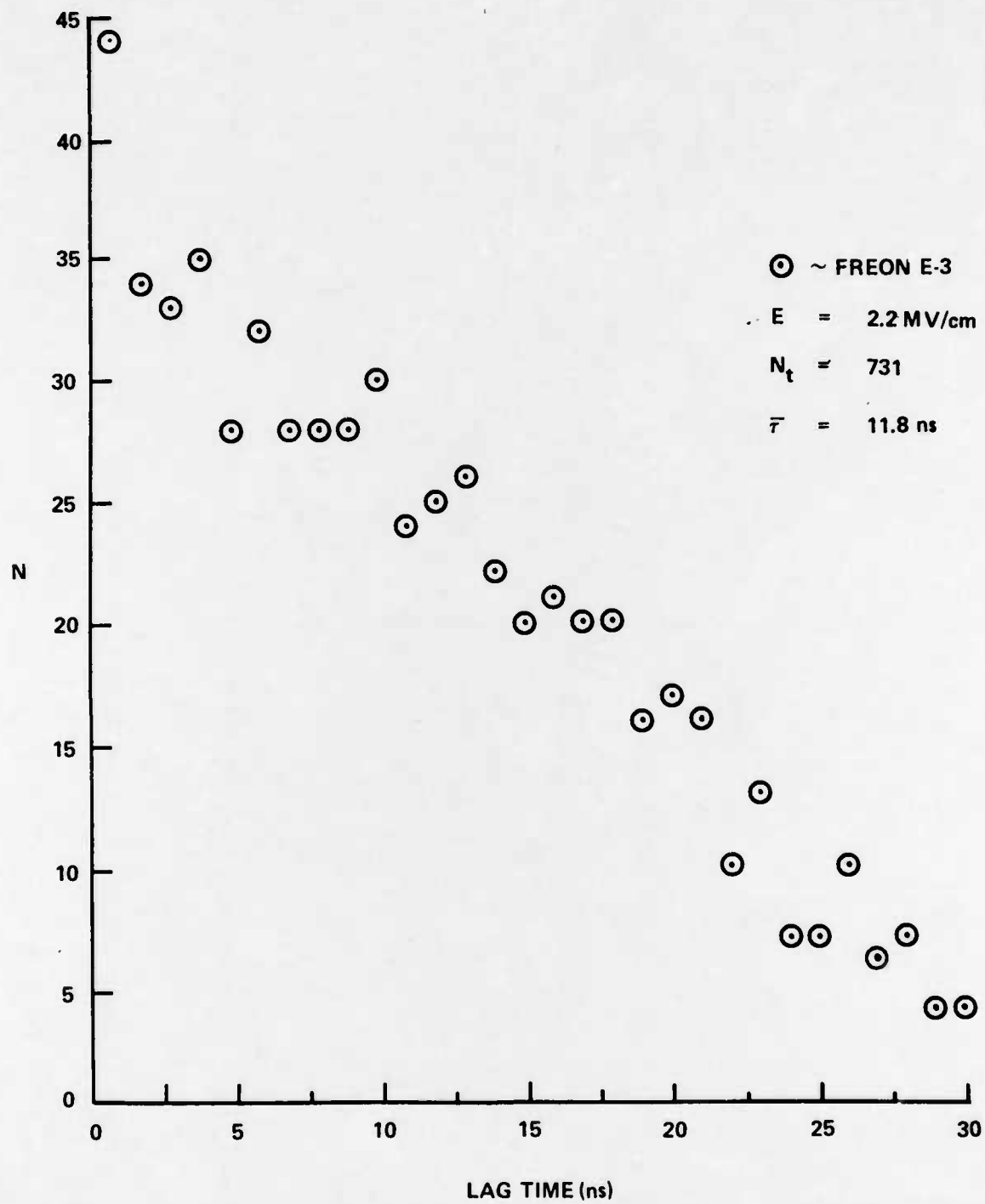
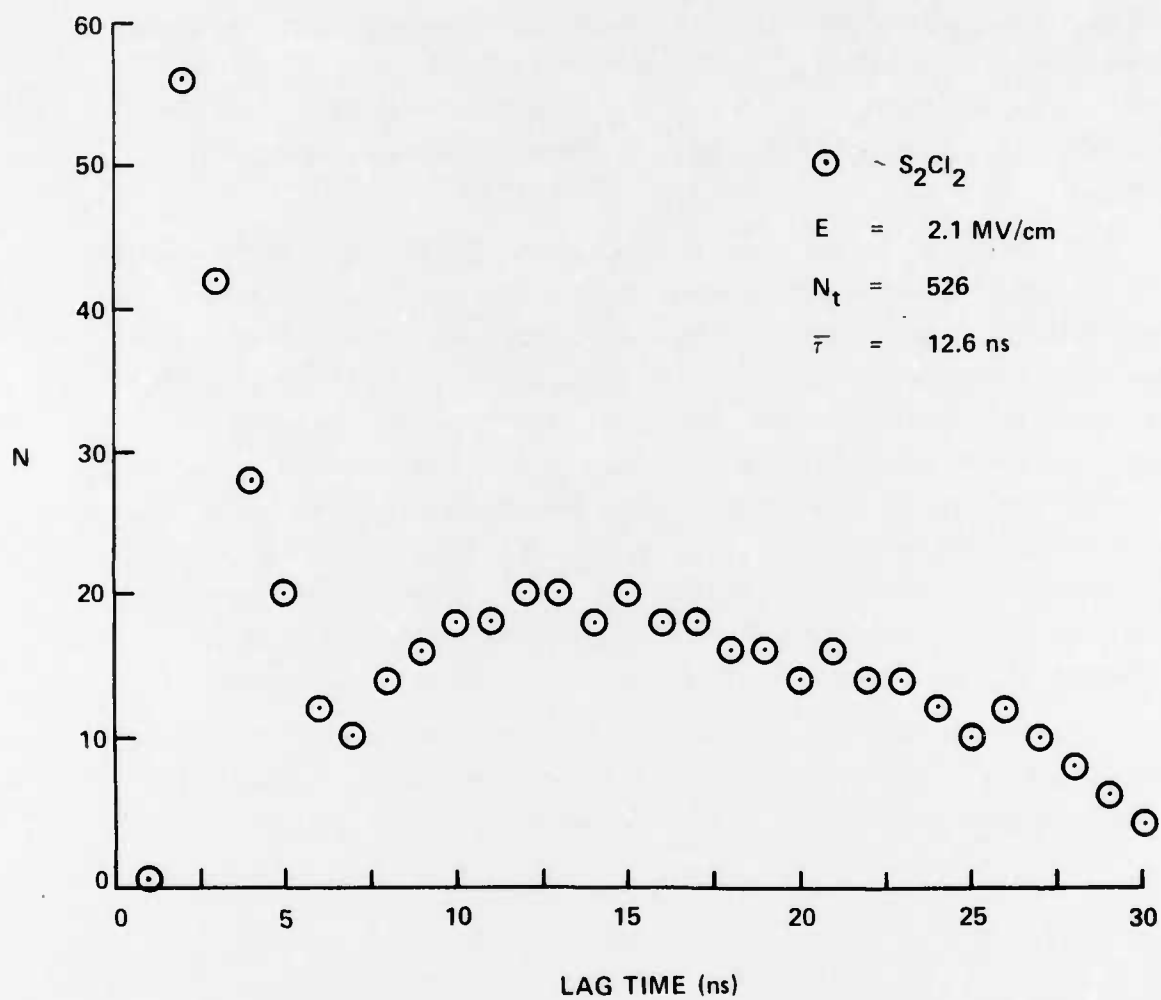


Figure 4. Probability Density Distribution in Freon E-3

Figure 5. Probability Density Distribution in S_2Cl_2

lesser field strengths and longer times. It is appealing to associate the non-Gaussian qualities of this distribution with the complexity, size and many degrees of freedom of the Freon E-3 molecule (molecular weight = 618).

The distribution observed in sulfur monochloride presents an interesting bimodal characteristic (Figure 5). A further observed peculiarity is that the peak at 2 ns seems to remain fixed at this location as the applied field is varied. The second maxima is quite sensitive to field, broadening rapidly at lower fields and depopulating altogether at field strengths only slightly above that applicable to Figure 5.

These results confirm previous findings regarding the Gaussian-like qualities of the formative lag time distributions in simple hydrocarbon liquids. However, the observed distributions of lag times in liquids composed of larger fluorocarbon molecules and smaller aprotic molecules are far from Gaussian. It is a widely held⁸ view that the initiating mechanisms take place at the electrodes. Therefore, it appears that these mechanisms may be strongly dependent upon the structure of molecules composing the liquid in the electrode interfacial region and that the incipient processes measured on a nanosecond time scale may be dominated by the response, e.g., orientation of such molecules to the applied field. Future studies are planned in which the lag time distribution characteristics will be determined for other liquids including, for example, a series of straight chain hydrocarbon liquids.

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